Central European Institute of Technology
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Tomographic artifacts: appearances, causes and corrections

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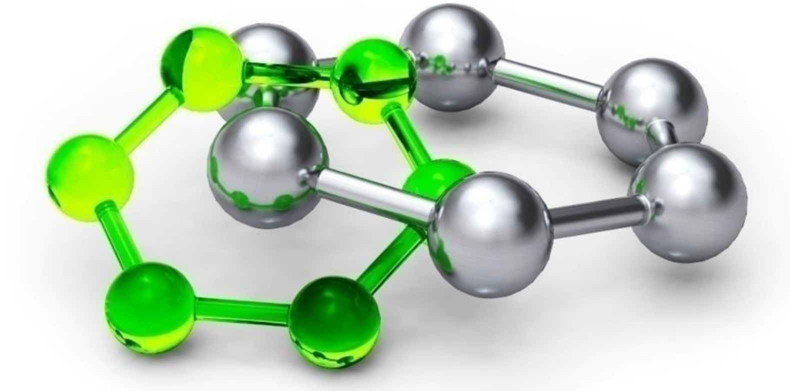


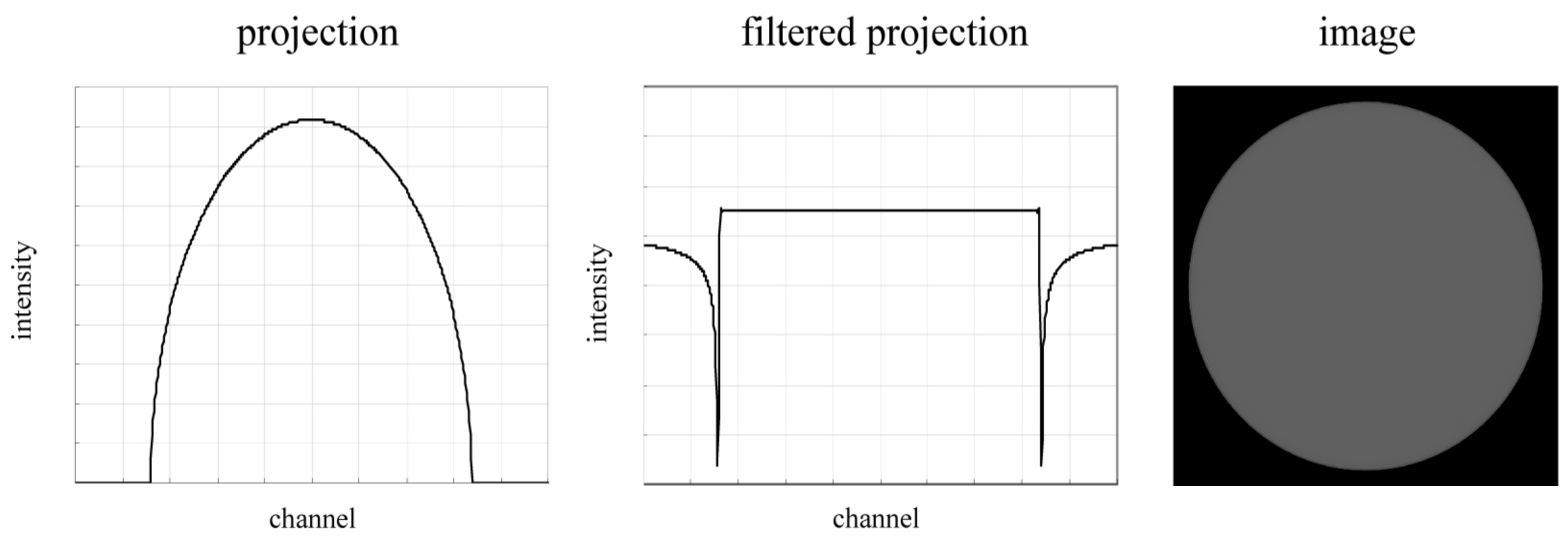
Appearances of image artifacts

What is an image artifact?

- Generally can be defined as discrepancy between the reconstructed values in an image and the true object
- CT is more prone to artifacts than conventional radiography → more projections
- Many causes:
  - Physics limitations
  - System design
  - Sample characteristic
  - Limitation of technologies
  - Non-optimal scanner
- Methods to combat image artifacts can be divided into 2 major classes:
  - Artifact avoidance
  - Artifact corrections

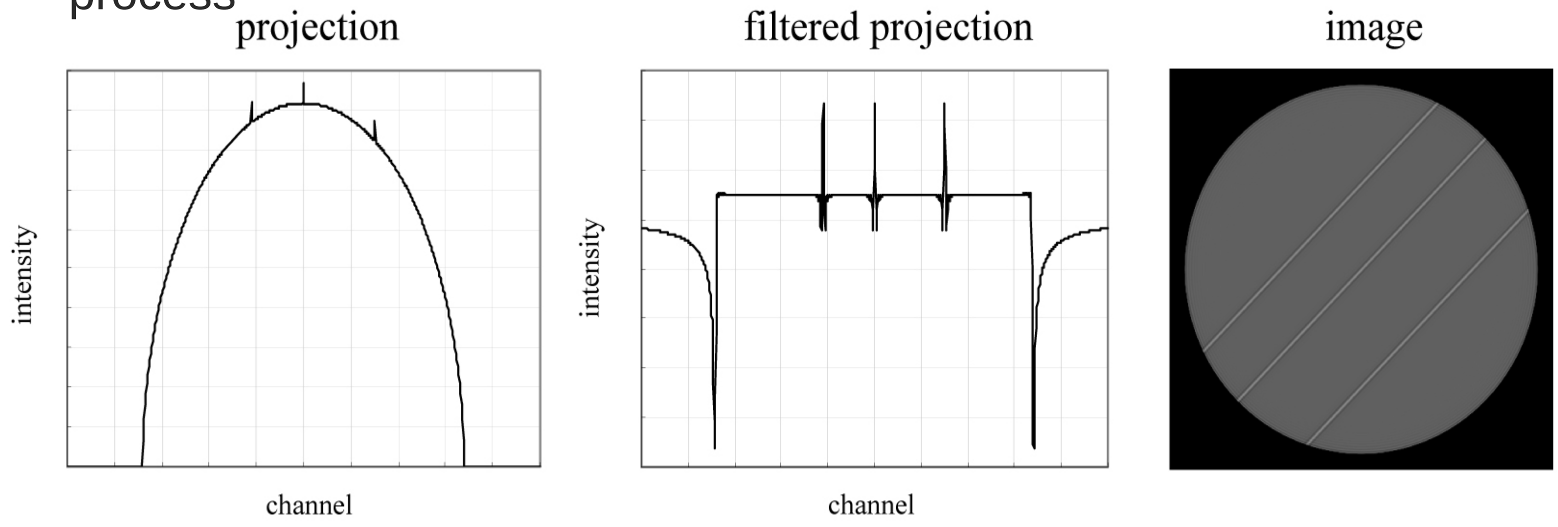
Appearances of image artifacts

- Generally 4 major categories of CT image artifacts:
  - Streaking
  - Shading
  - Rings and bands
  - Miscellaneous
- As an example is shown simulated water phantom



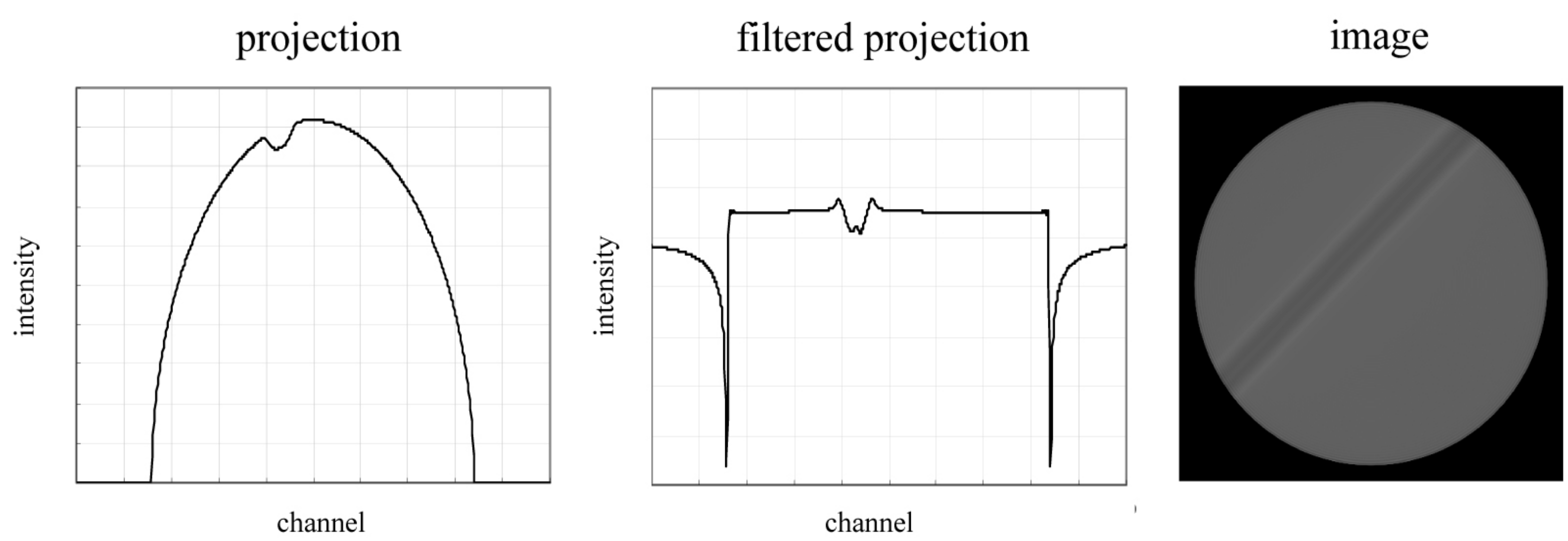
Streaking artifacts

- Straight lines across the image
- usually caused by an inconsistency in the isolated measurements
- After the filtering process, the errors appear to be significantly enhanced → ramp filter:
  - Errors in the projection are overshooted and undershooted at locations of discontinuity after filtering
  - These patterns are mapped to bright and dark lines by the back projection process



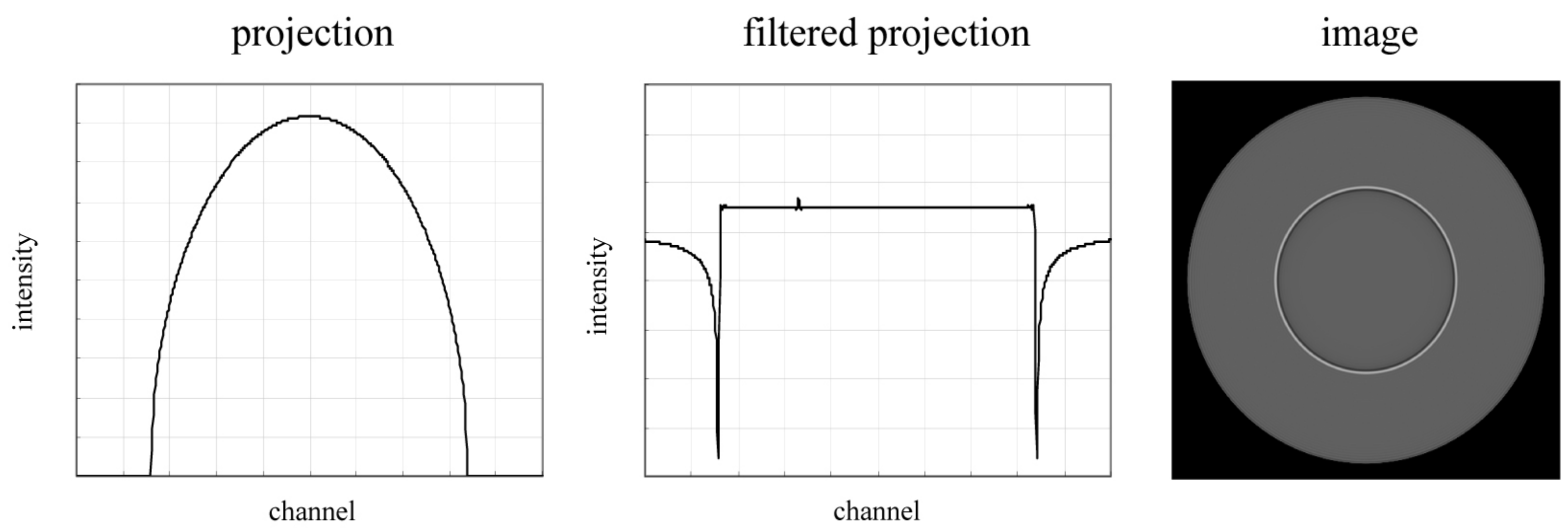
Shading artifacts

- Often appear near objects of high contrast
- Unlike streaking artifacts, shading artifacts are generally caused by a group of channels or views that deviate gradually from the true measurements



Ring and band artifacts

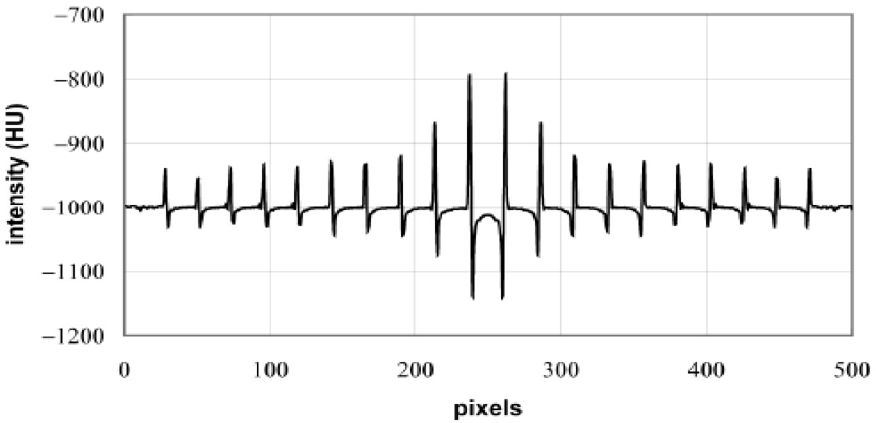
- Either full rings or arcs
- Mainly third-generation CT phenomenon
- If the same error is persistent over a range of views, the tail portions of the streaks are canceled and an arc or ring is generated
- Although the magnitude of the projection error is very small, the intensity of the ring is very high

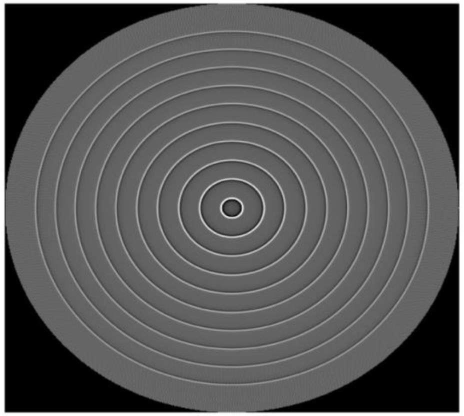


- The total intensity integrated along the circumference of the ring Q equals the product of the channel error intensity ε and the number of views n. The intensity of the ring in the image c is:

$$c = \frac{Q}{2\pi r} = \frac{n\varepsilon}{2\pi r}$$

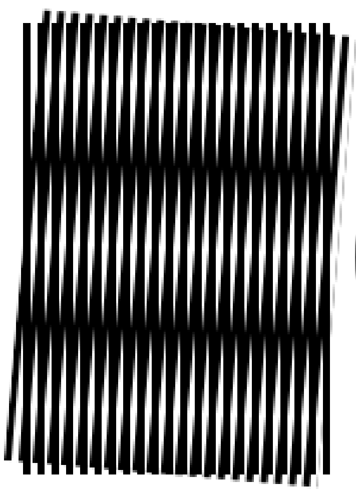
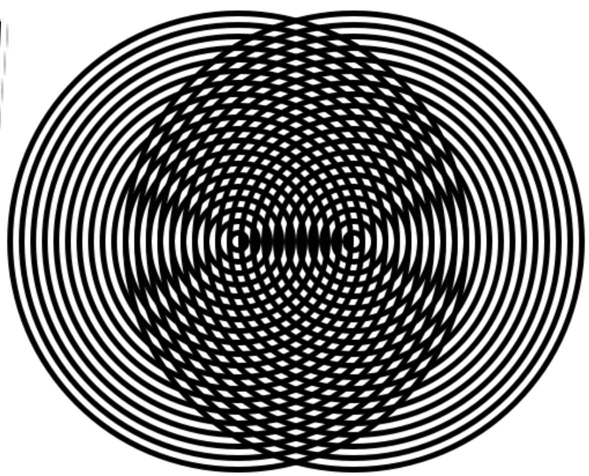
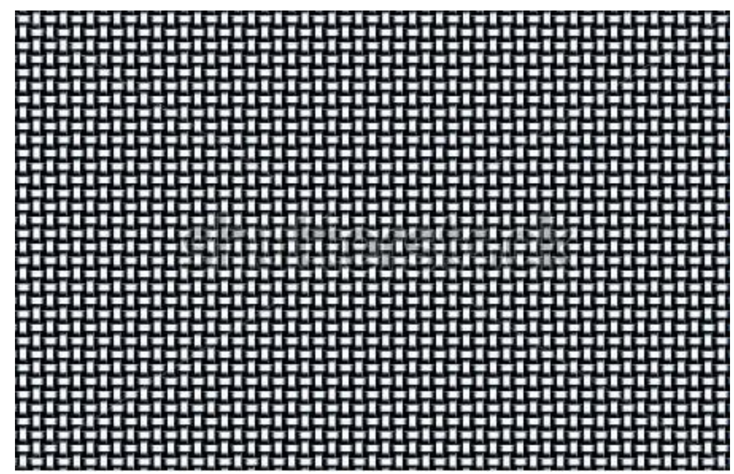
- the intensity of the ring artifact is inversely proportional to the radius of the ring.





Miscellaneous artifacts

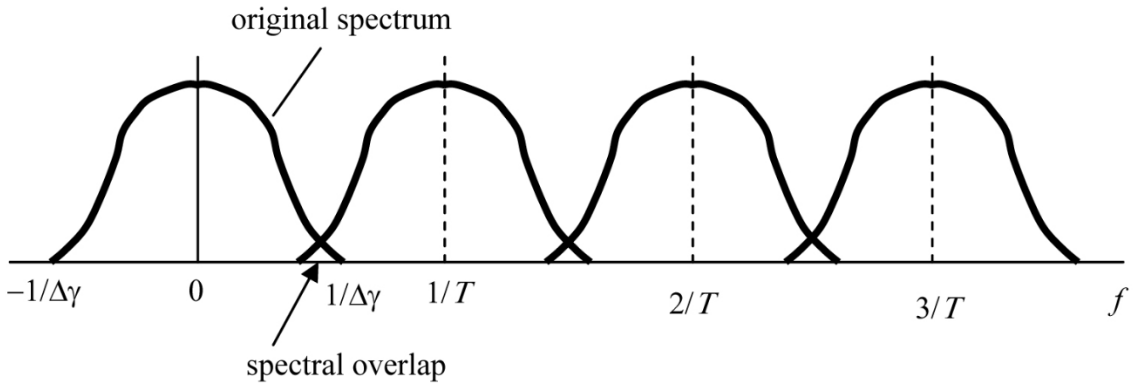
- Various less-common artifacts
- The basket weave artifact
- Moiré pattern
  - superimposed pattern created, for example, when two identical patterns on a flat or curved surface are overlaid while displaced or rotated a small amount from one another.

Artifacts related to system design

Aliasing

- The process of spectral overlap $\longrightarrow$ aliasing



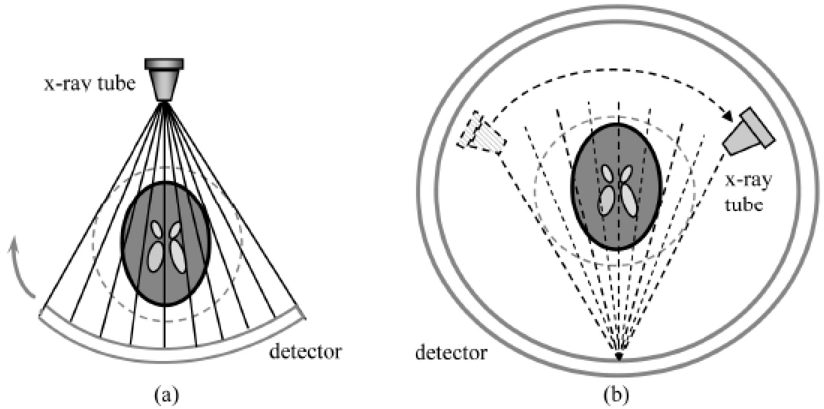
The original spectrum is replicated at an interval *(1/T)*, where *T* is the spatial sampling distance (equal the detector channel spacing). If *(1/T)* is too small, overlaps occur between shifted spectrums, and aliasing artifacts result.

- To avoid aliasing, the original data must be sampled at a rate of at least twice the highest spatial frequency contained in the signal.

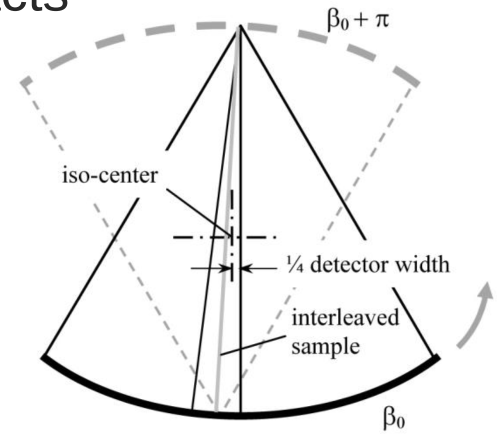
Shannon-Nyquist sampling criterion

$$T \leq \frac{\delta}{2}$$

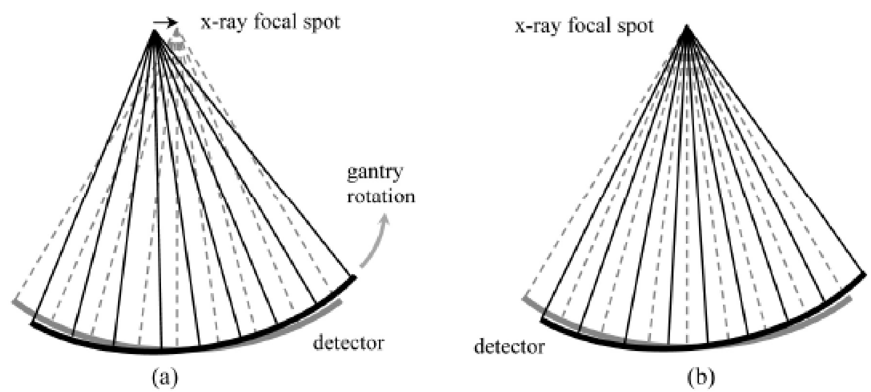
- To combat aliasing, the concept of a fourth-generation CT scanner was proposed



- For third-generation scanners, various approaches to combat aliasing artifacts

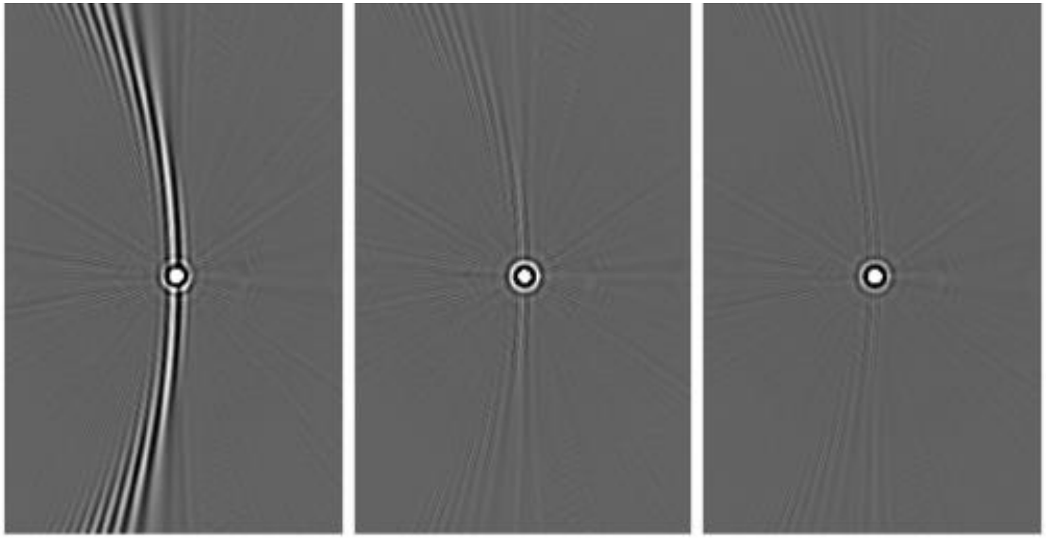


quarter detector offset



focal spot wobble

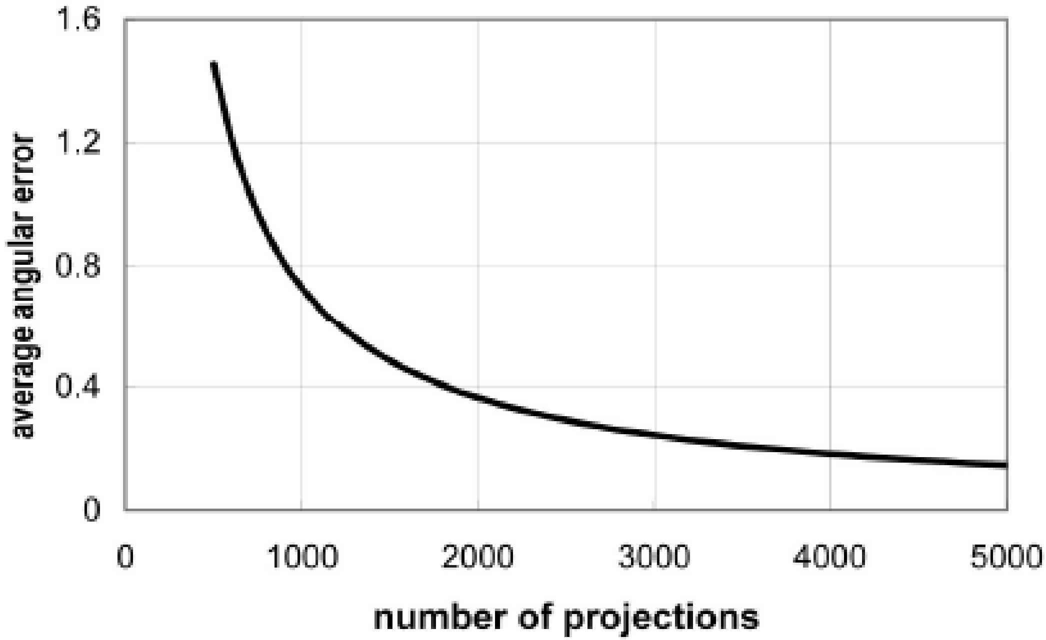
- Simulated projections of a 0.1 mm diameter wire placed 5 cm off the iso-center. The projection is undersampled → aliasing streaks



isocenter and iso-channel in alignment *quarter detector offset* *focal spot wobble*

- Generally there are two types of alliasing → *projection aliasing*, *view aliasing*

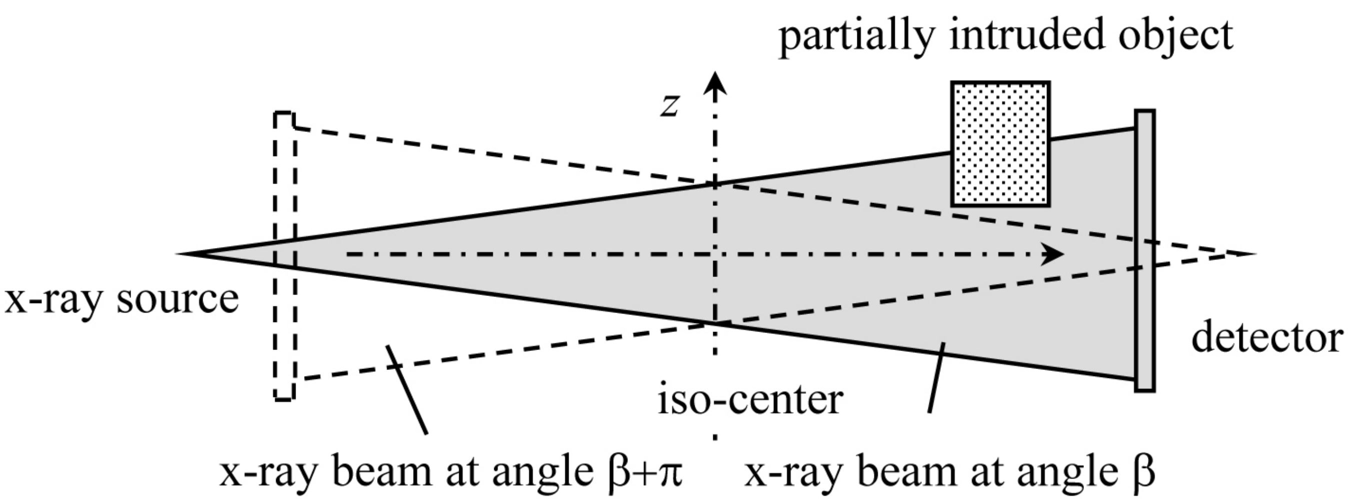
- View aliasing artifacts are typically a set of streaks emanating from high-density objects



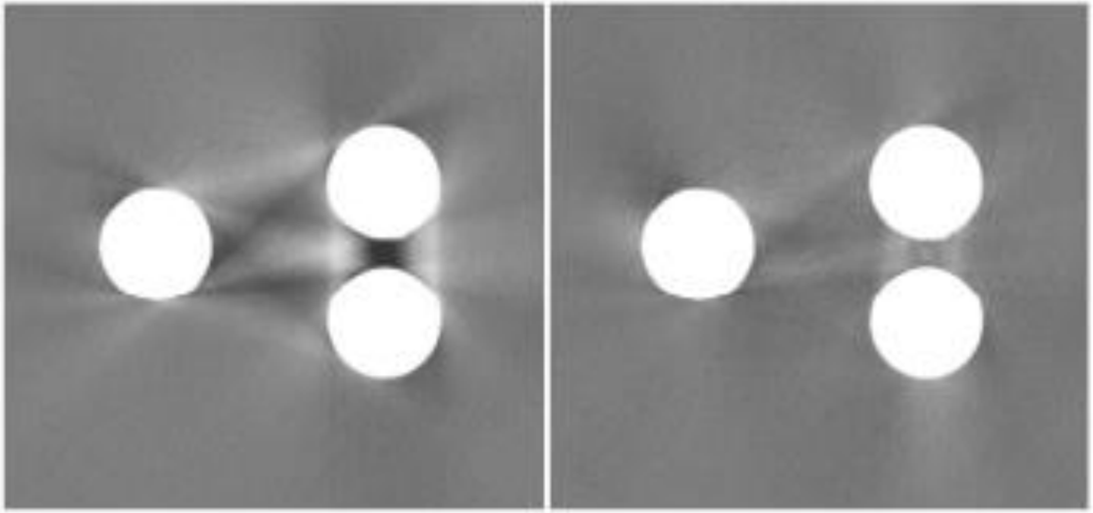
- To combat view aliasing artifacts
  → the view-sampling rate is increased to collect more projection views, or algorythmic compenstation is used

Partial volume

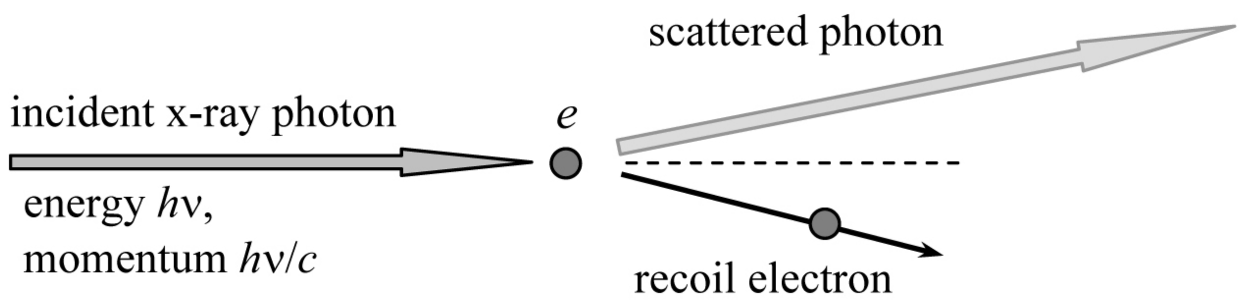
- Partial volume occurs when an object partially intrudes into the scanning plane.
- Larger slice thickness → higher risk of partial-volume occurrence
- Two major factors cause partial-volume artifacts:
    - projection inter-view inconsistency
    - projection intraview inconsistency



- Partial volume artifacts are predominately shadows cast by high-density objects into lower density and air regions
- The best method to combat partial-volume artifacts is to use thin slices
- Computer algorithms can be used to reduce partial-volume artifacts. The final image is obtained by subtracting the error image from the original one.



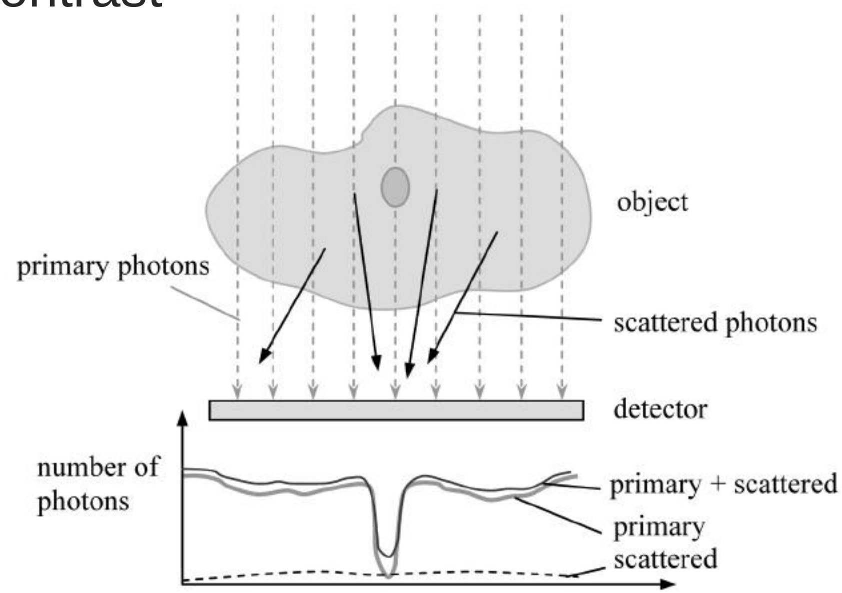
Scatter



- Compton scattering ⟶ Portion of the detected signals is generated from the scattered photons ⟶ Shading or streaking artifacts in the reconstructed image and reduced contrast

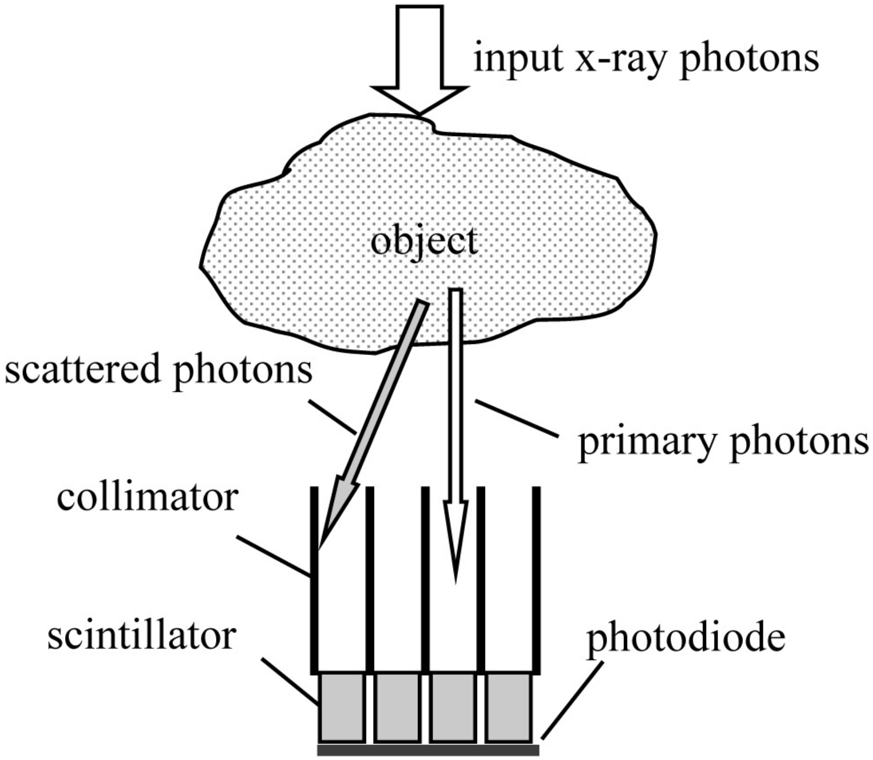
- To quantify the scatter, the **scatter-to primary ratio** is used

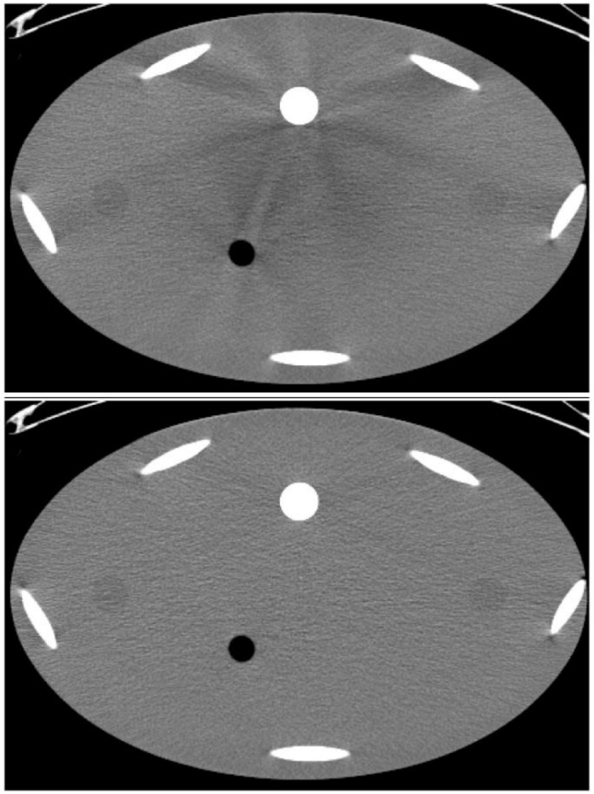
- Lower scatter-to-primary ratio ⟶ better system performation



CEITEC

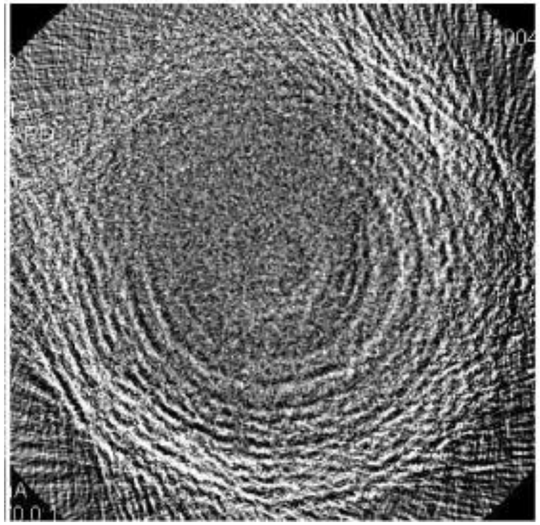
- Most CT designers combat scatter by preventing the scattered radiation from reaching the detector
- In third-generation CT scanners a collimator is placed near the detector surface





Noise-induced streaks

- Excessive photon noise can cause severe streaking artifacts
- Main causes:
  - improper selection of scanning parameters
  - CT scanner construction limitations
  - electromagnetic interference between different components of the scanner

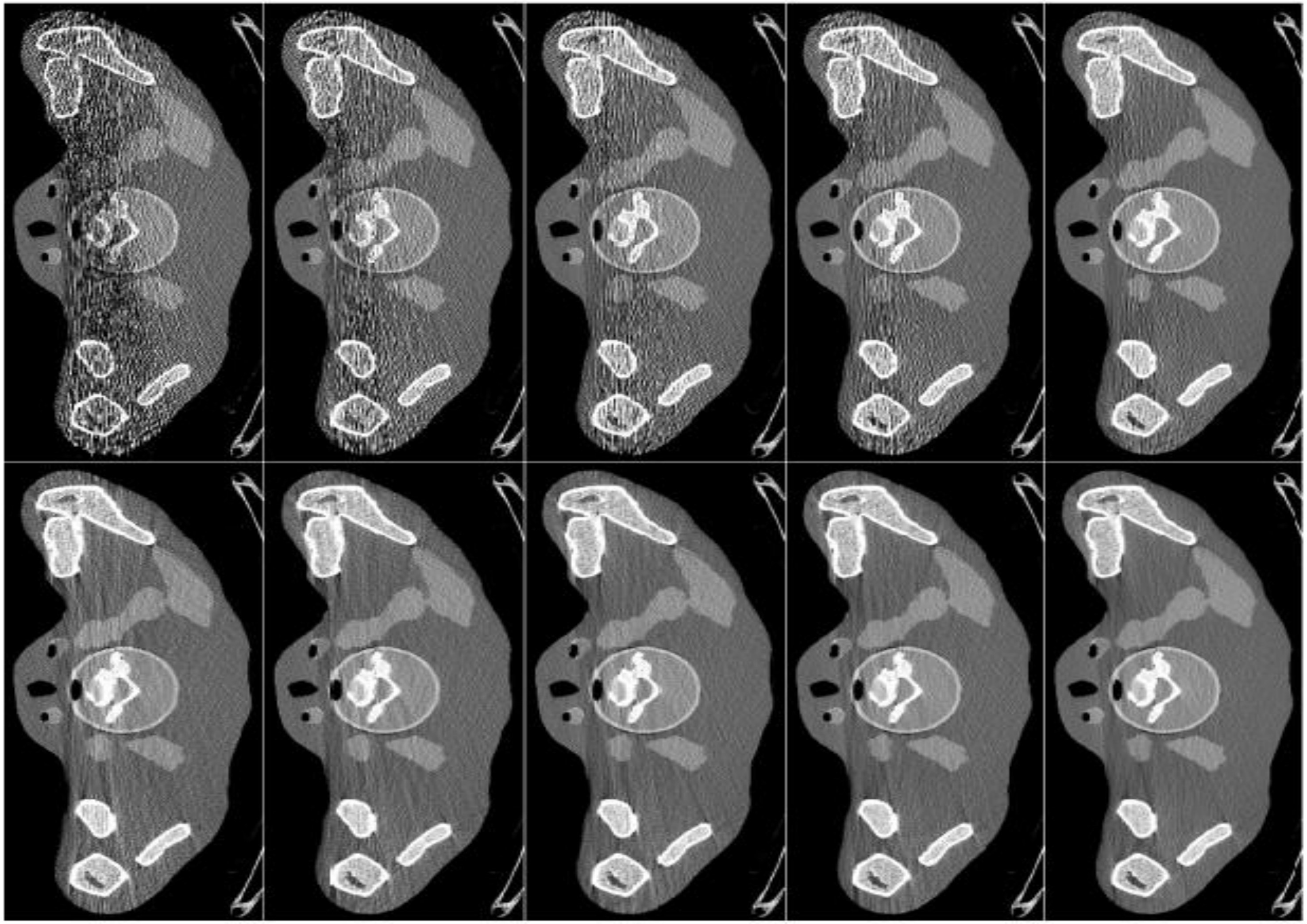



- In general, the variance of a detected signal σ^2 can be expressed by equation:

$$\sigma^2 = \sigma_\varepsilon^{\,2} + \sigma_q^{\,2} \cong \sigma_\varepsilon^{\,2} + \omega x$$

- σ_ε - electronic noise floor for the data acquisition system; σ_q - x-ray photon quantum noise; ω - system gain factor; x - output at the detector

- To combat noise induced streaks $\longrightarrow$ Non-linear and addaptive signal-processing techniques:
  - To minimize resolution loss, minimal filtering is applied to the channels that received a high x-ray flux
  - Filtering increases with decreasing x-ray flux



no filtering

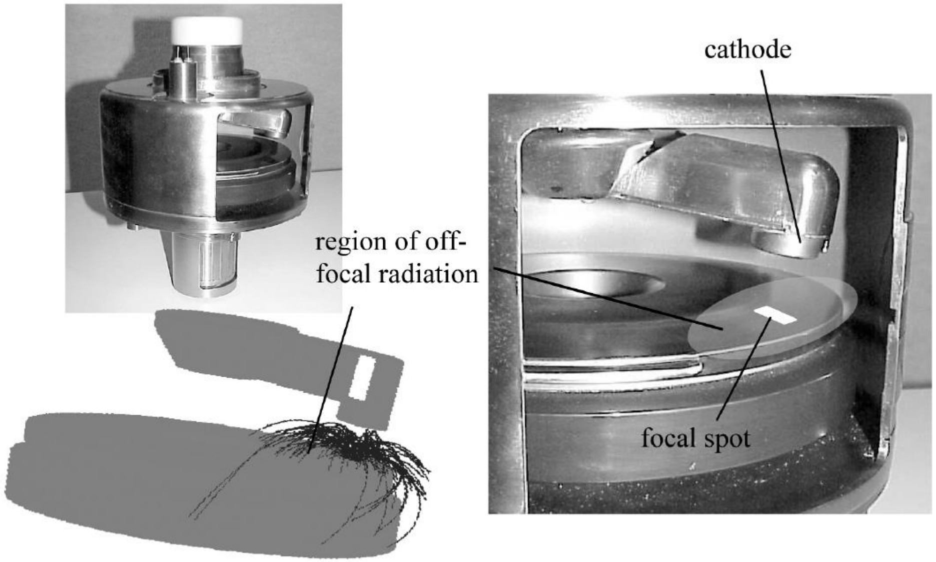
addaptive filtering

40 mA 60 mA 80 mA 100 mA 200 mA

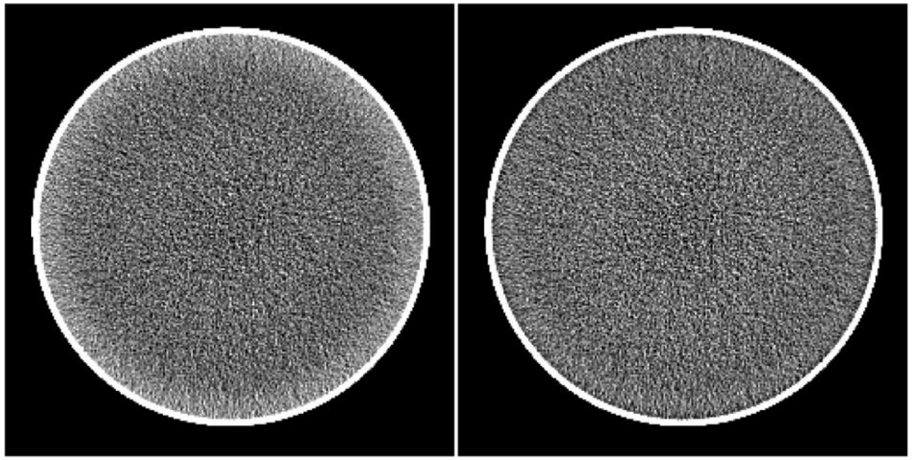
Tomographic artifacts induced by X-ray

- Off-local radiation

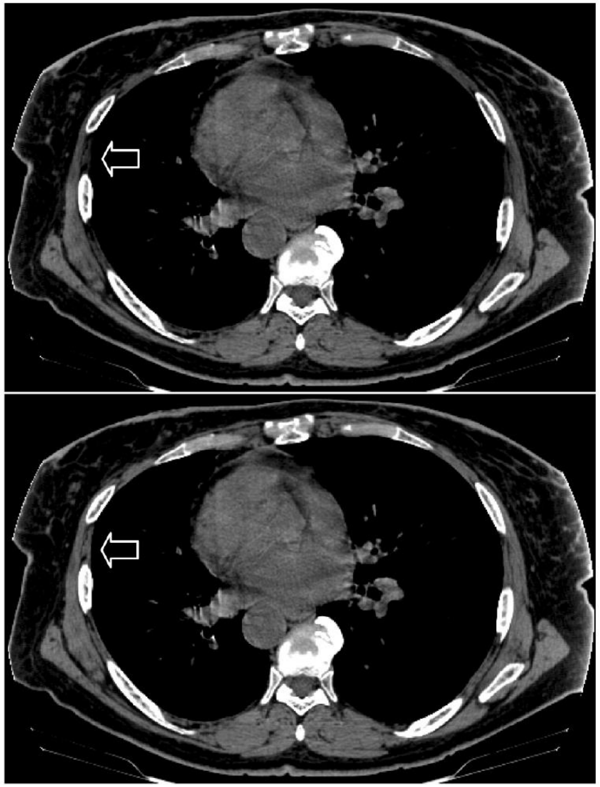
secondary electrons and field-emission electrons



Therefore, from a mCT imaging point of view, the x-ray source can be modelled as a high-intensity centre spot surrounded by a low-intensity halo.



(a) (b)

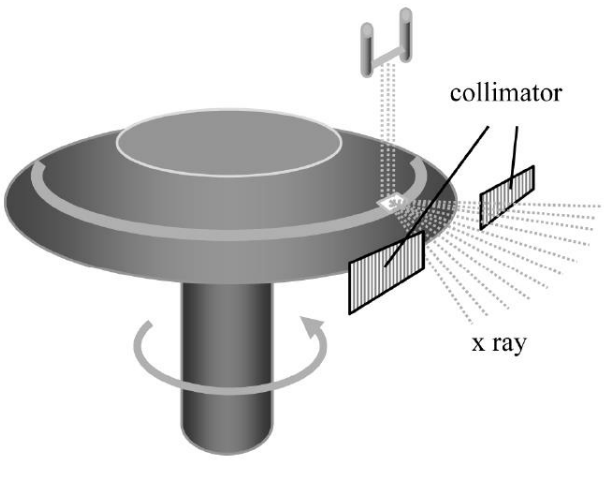


(a)

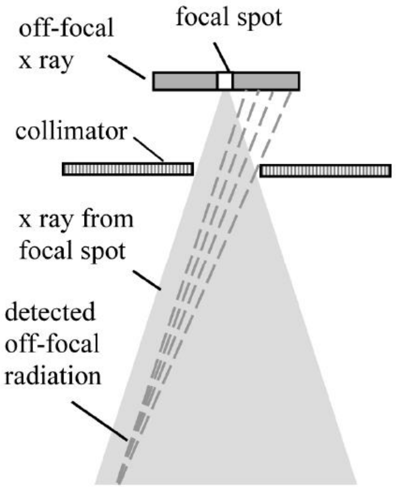
(b)

Off-focal radiation can be partially controlled by:

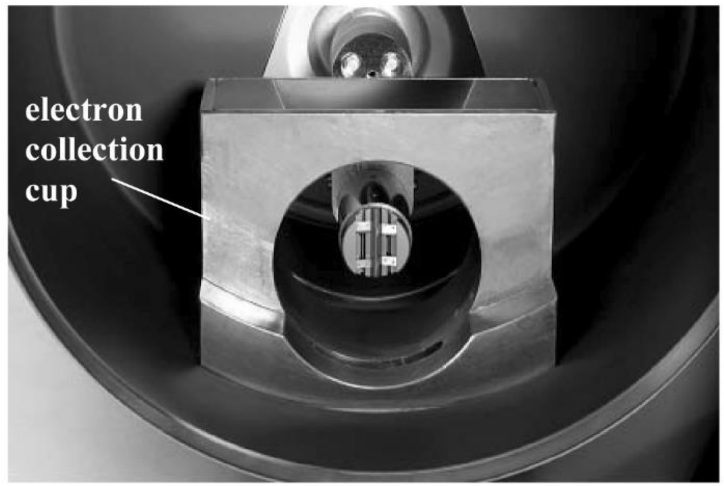
1. Placing *collimators* outside the x-ray tube. For example, a lead diaphragm with a small port can be placed outside the tube glass envelope to stop some of the off-focus beam spread.
2. *Beryllium window*.
3. *Software correction*.
4. New technologies as *electron collection cup* …



(a)

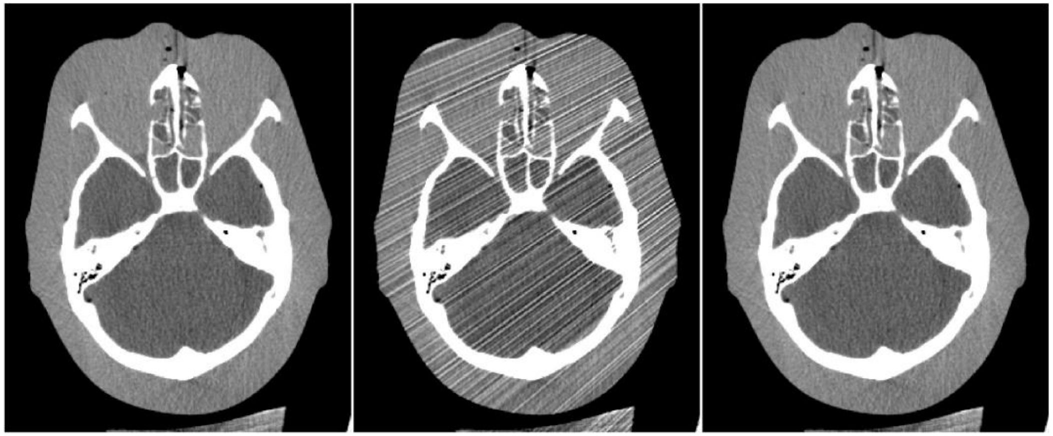


(b)



Tube arcing

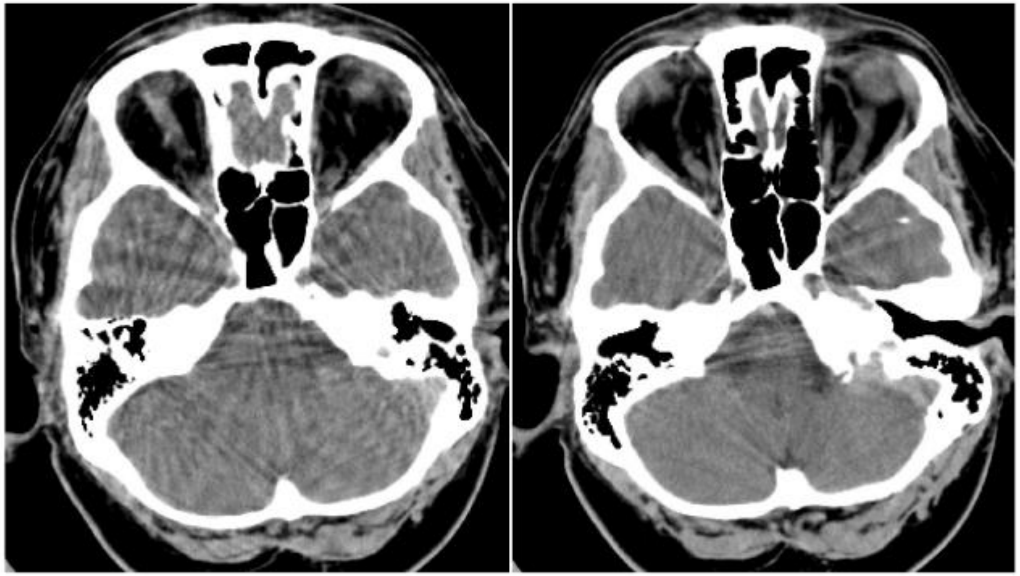
When impurities are present in the x-ray tube, a temporary short-circuit can result that is often called tube arcing or tube spit



(a) (b) (c)

- The tube arcing or tube-spit can easily fixed with:
  - Continue monitoring of the power-supply resource.
  - Use of algorithmic correction schemes.

Tube rotor wobble



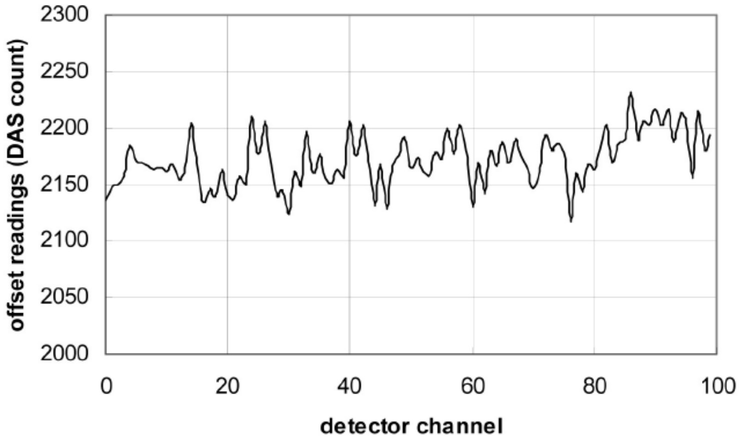
(a) (b)

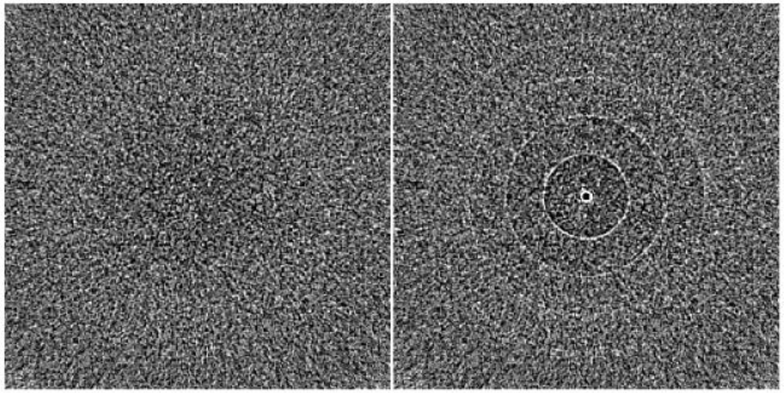
In some cases, streaking artefacts are caused by mechanical failure. This can be the result of a lack of rigidity in the gantry, a mechanical misalignment, or x-ray tube rotor wobble.

The best approach to fix this type of problem is to replace the faulty component.

Detector-induced artifacts

- Offset, gain, nonlinearity, and radiation damage



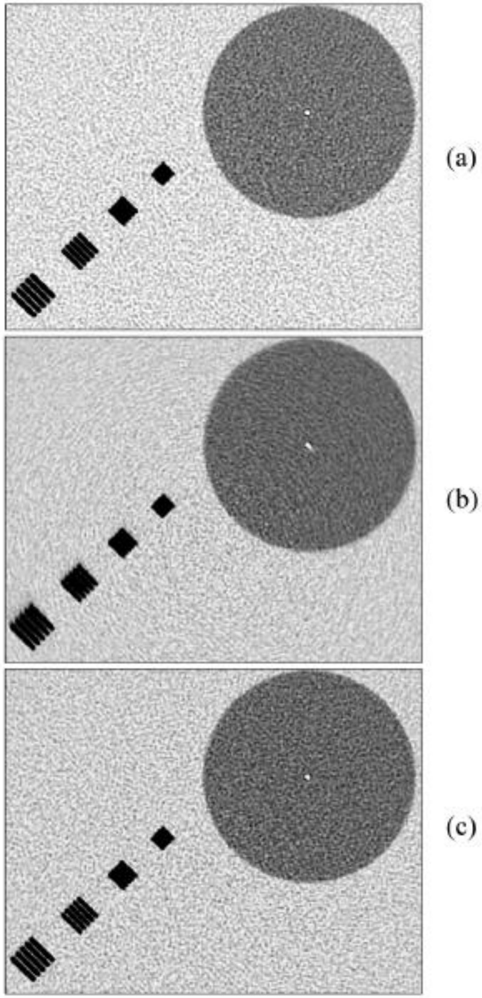


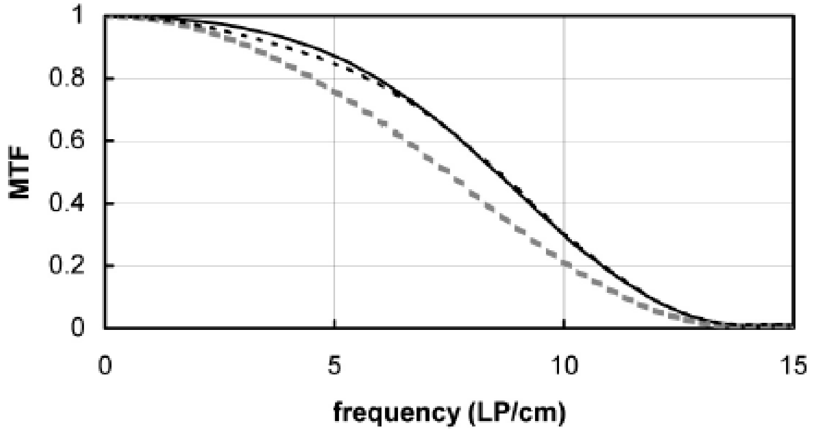
(a) (b)

- To compensate for the gain variation from channel to channel and over time, most CT manufacturers use a calibration technique called air scans. In this process, a set of scans is acquired without any object inside the scanning FOV. If we assume that the x-ray flux impinging on all detector cells is the same, the detector cell gain should be proportional to its measurement in the air scans.
- The subsequently collected sample scans are divided by the appropriate gain vector to produce gain-normalized scan data.
- This process must be performed only once per day for current CT scanners.

Primary speed and afterglow

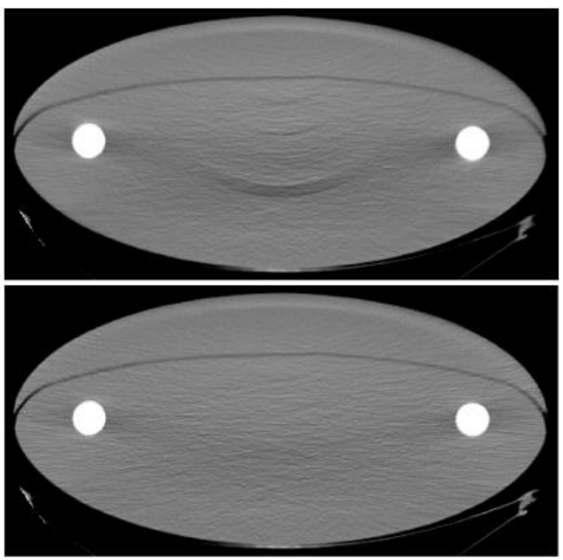
- Nearly all solid state scintillation materials exhibit certain levels of signal decay and afterglow.
- If we expose a solid state detector to x-ray photons for a period of time and swiftly shut off the input x ray, the detector output does not reach zero immediately. The residual signal is sustained from a few microseconds to a few hundred milliseconds.
- Then, there is a decay components with short time constants, called as the **primary speed of the detector**, and there is another decay with long time constants, the **afterglow of the detector**.
- The primary speed of the detector impacts mainly the spatial resolution of the reconstructed images, while the afterglow components primarily affect image artefacts.





Reconstructed images of a GE Performance phantom (a) scanned at 2.0-sec scan speed, (b) scanned at 0.5-sec scan speed without detector decay correction, and (c) scanned at 0.5-sec scan speed with detector decay correction.

- The more serious image artifacts are caused by afterglow components with long time constants.



(a)

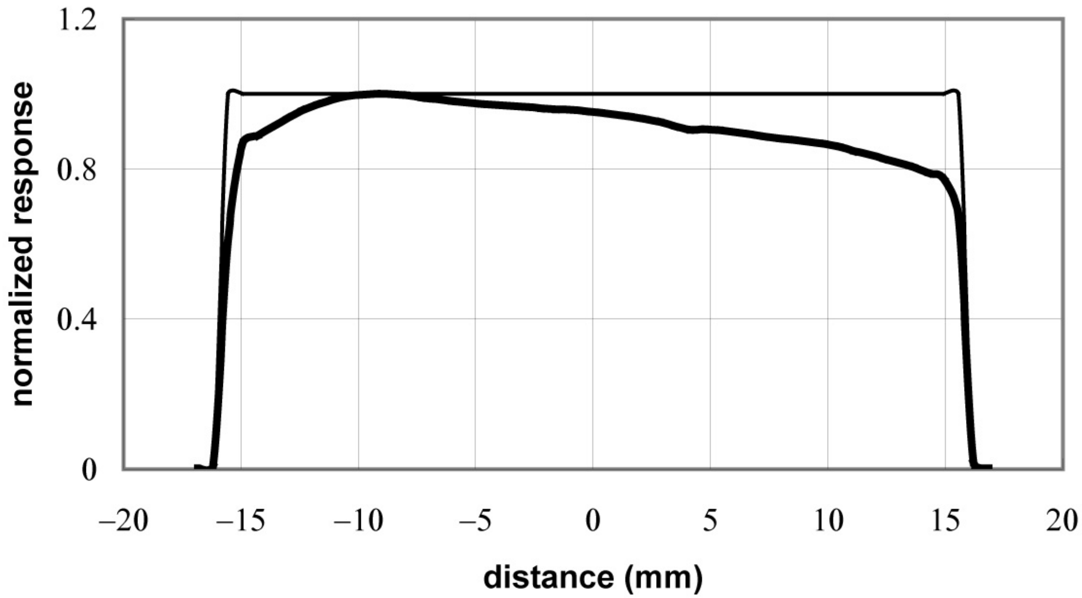
(b)

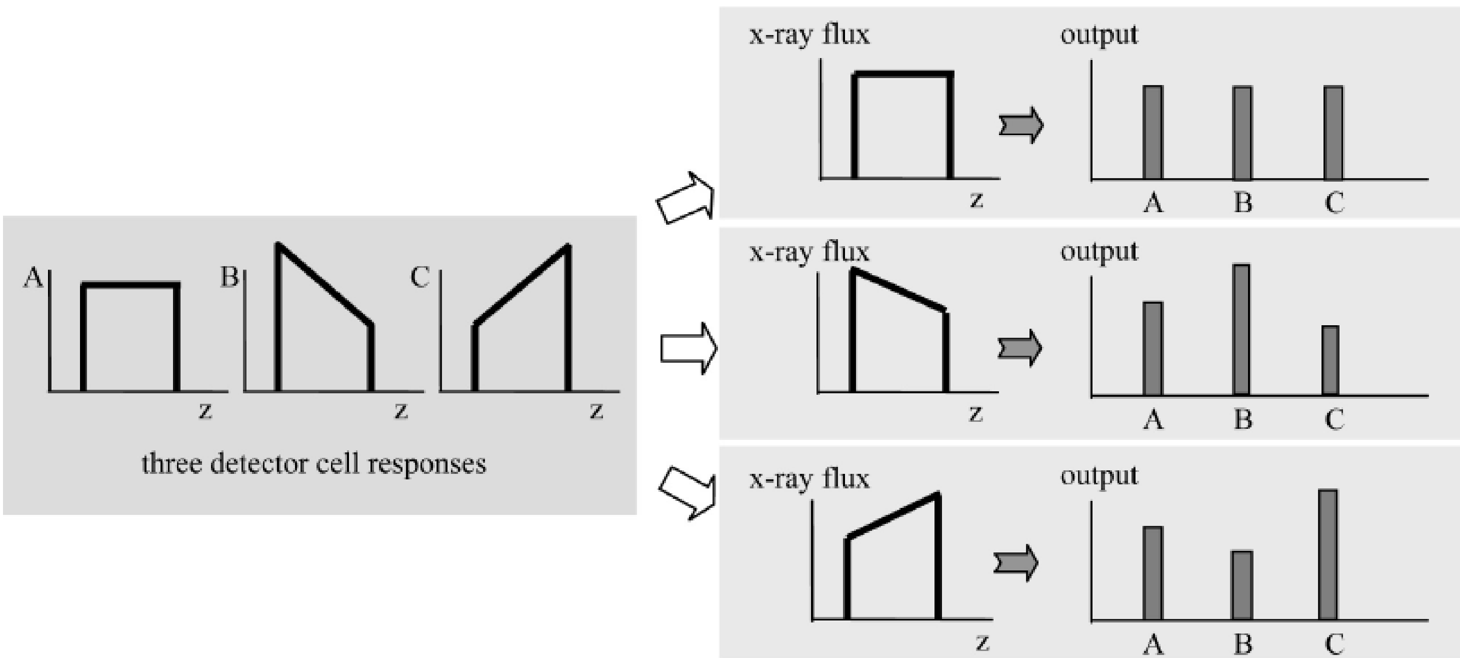
Several methods are available to combat image artefacts related to scintillator decay. The best method is to remove the root cause of the artifacts. Other approach is doping the scintillators with rare-earth materials.

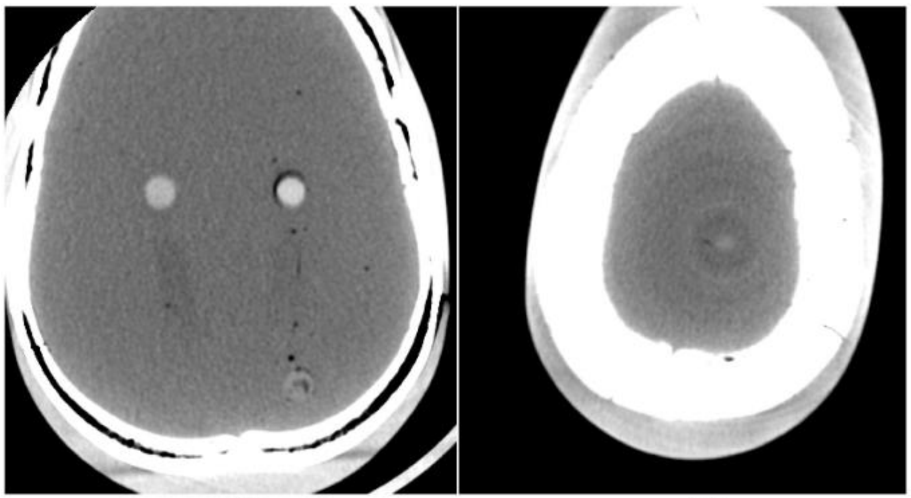
$$x(k\Delta t) = \frac{y(k\Delta t) - \sum_{n=1}^{N} \beta_n e^{\frac{-\Delta t}{\tau_n}} S_{nk}}{\sum_{n=1}^{N} \beta_n}$$

$$S_{nk} = x\left[(k-1)\Delta t\right] + e^{\frac{-\Delta t}{\tau_n}} S_{n(k-1)} \text{ and } \beta_n = \alpha_n \left(1 - e^{\frac{-\Delta t}{\tau_n}}\right)$$

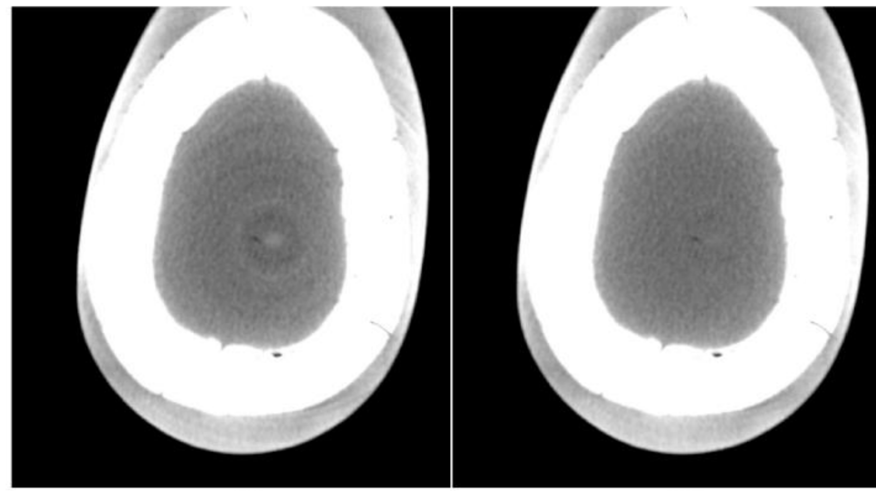
Detector response uniformity




A
B
C
z
z
z
three detector cell responses
x-ray flux
output
z
A
B
C
x-ray flux
output
z
A
B
C
x-ray flux
output
z
A
B
C



(a) (b)



(a) (b)

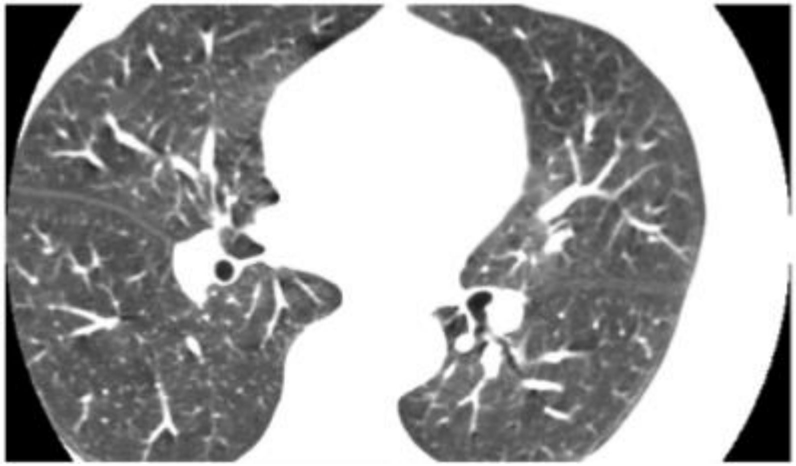
Tomographic artifacts induced by patient

Motion artifacts

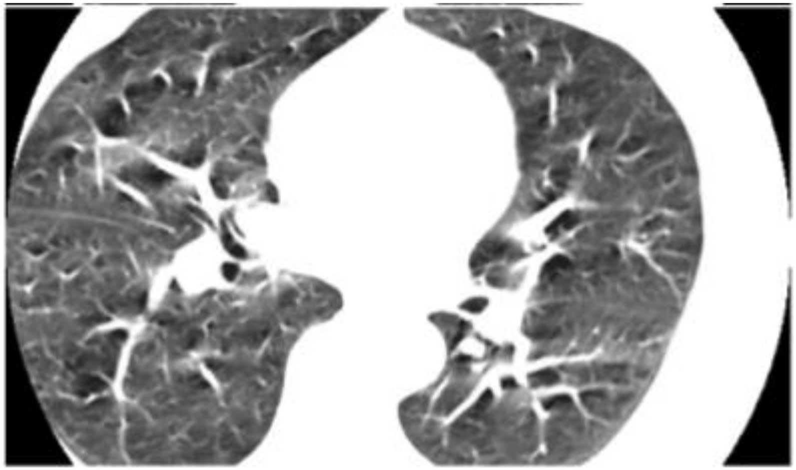
- Object of interest can move, expand, shrink within the scanning plane
- Hospital CT: moving of patient, organs: respiratory motion, swallow motion,…
- Laboratory CT: bad fixation of sample, thermal expansion or desiccation of sample

- Respiratory motion artifact

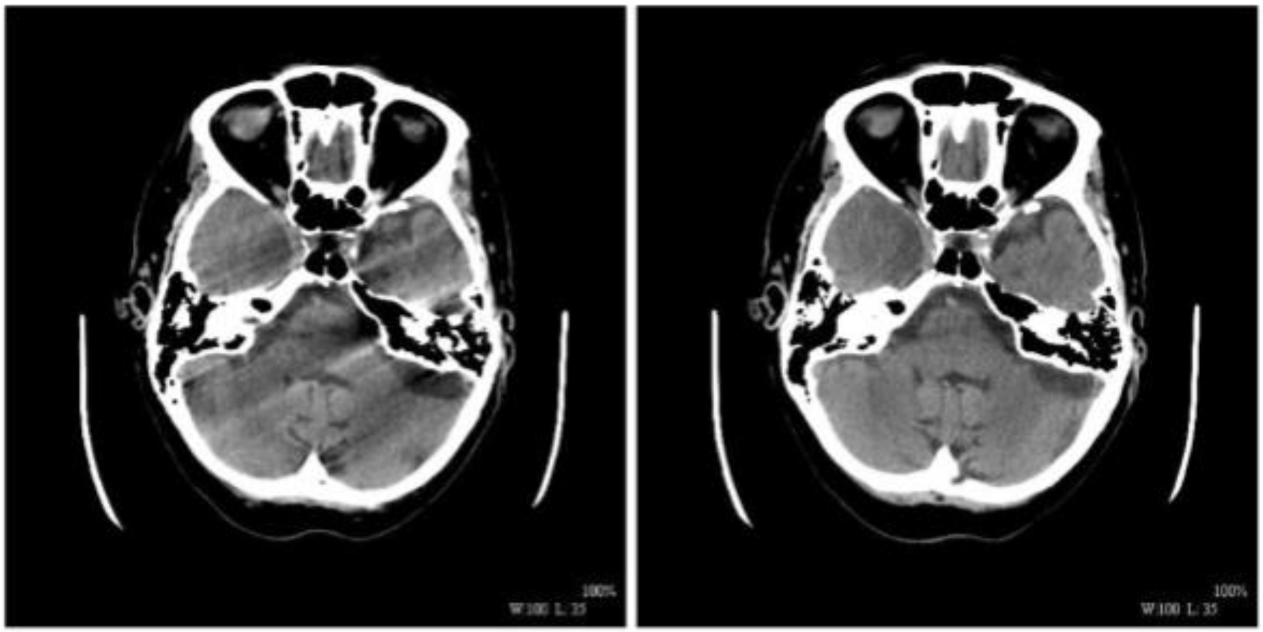
(a)



(b)



- Patient’s head motion



(a) (b)

Preventing of motion artifact, correction

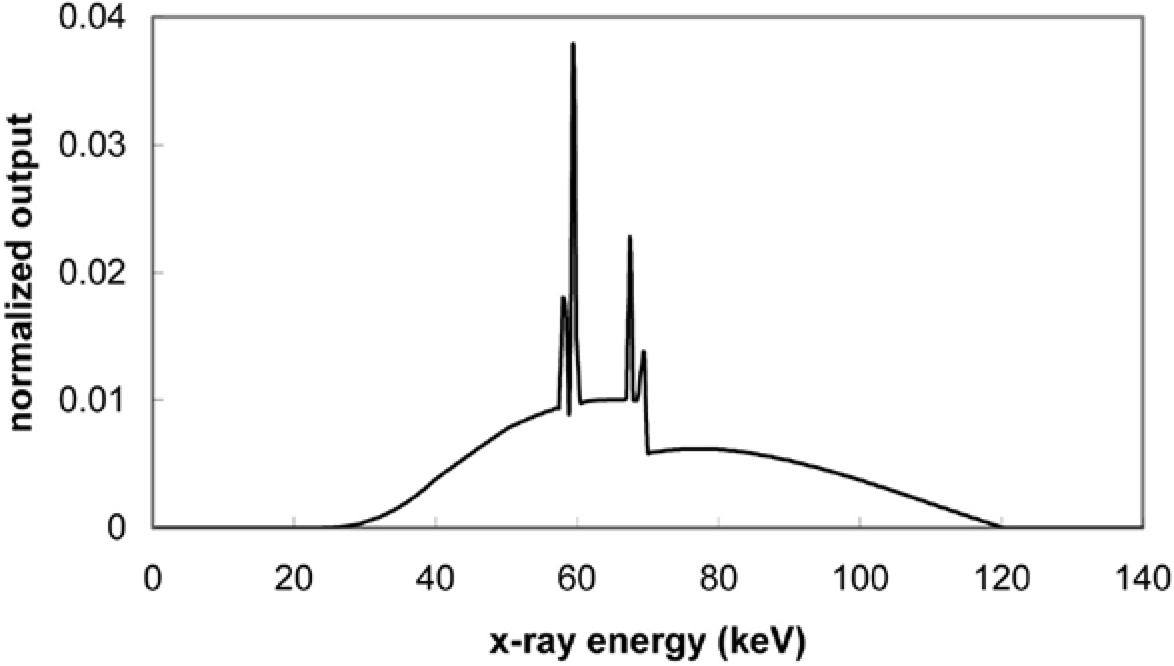
- Preventing: to stabilize the patient’s head, fixation of the sample,…
- Correction: algorithms based on weigh functions
- Slow movements: refrential images obtained from different angles (for example 45°)

Beam hardening

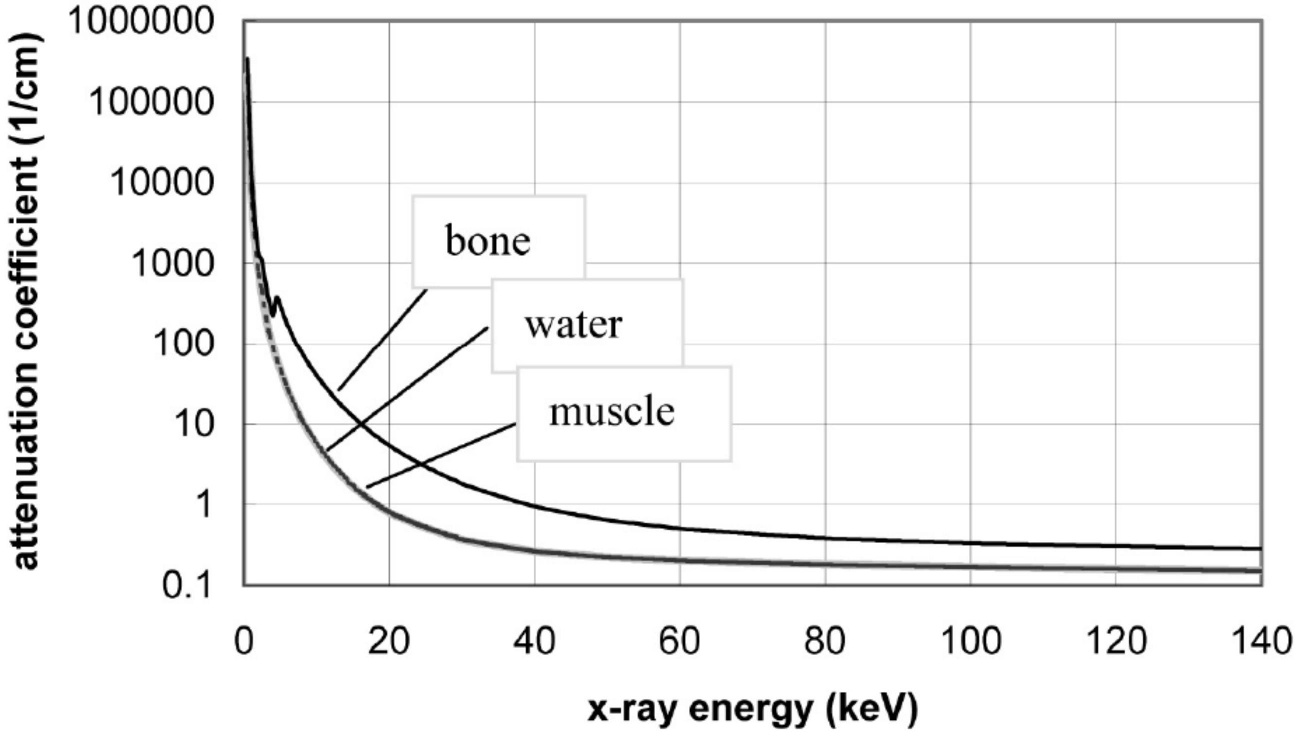
- This effect is caused by polychromatic X-ray beam
- Most material absorb low-energy X-rays better than high-energy
- Beer Lambert law for monoenergetic X-ray:

$$I_E = I_{0,E} e^{-\int \mu_{E,S} ds}$$

- X-ray tube energy spectrum



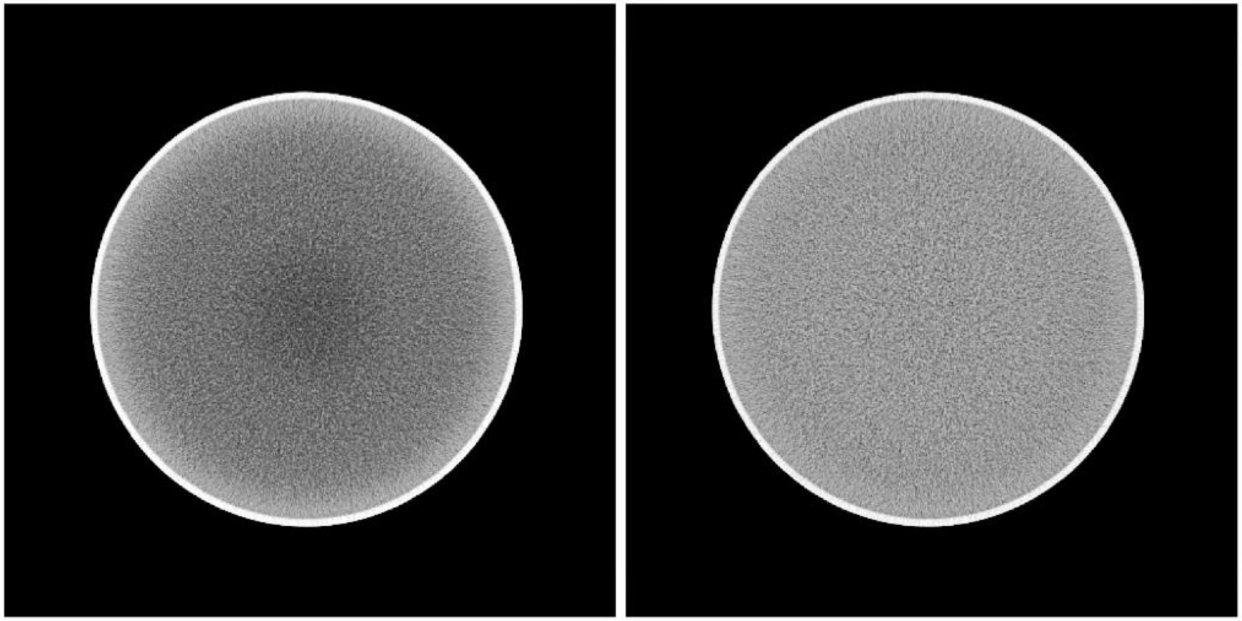
- Linear attenuatin coefficient for bone, water and muscle as a function of X-ray energy



Correction of BH

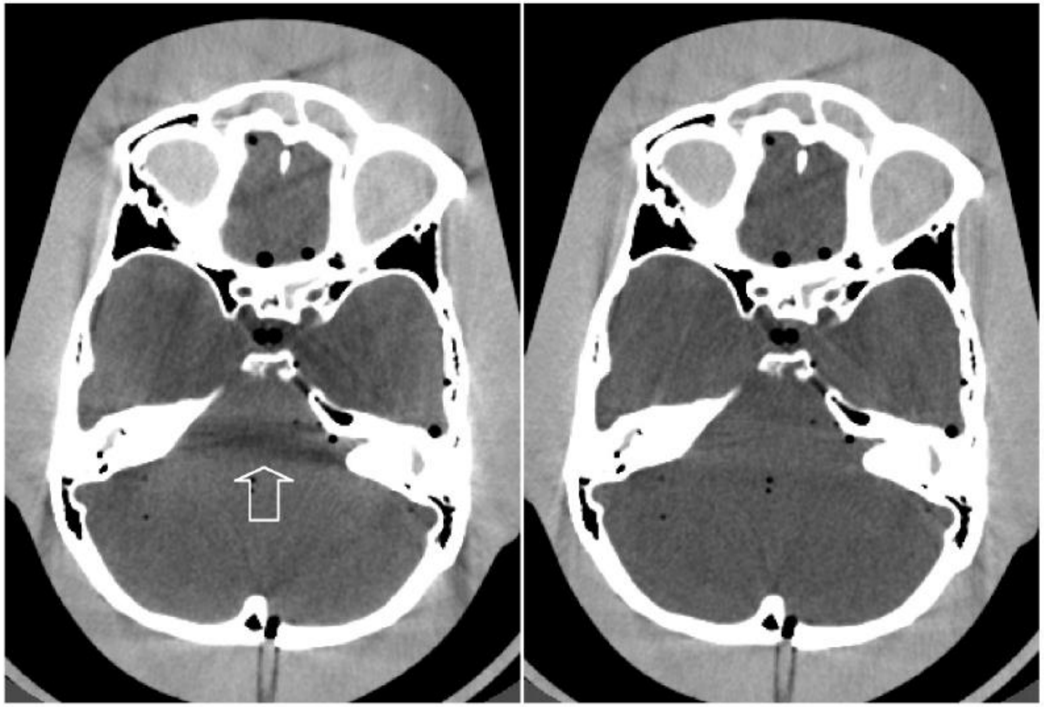
- Beam filtration: thin layer of aluminium, copper, or brass between sample and X-ray target (flat filter)
- Softwares- water BH correction, bone BH correction

- Reconstructed images of a 35 cm water phantom



(a) (b)

- Image of a human skull phantom

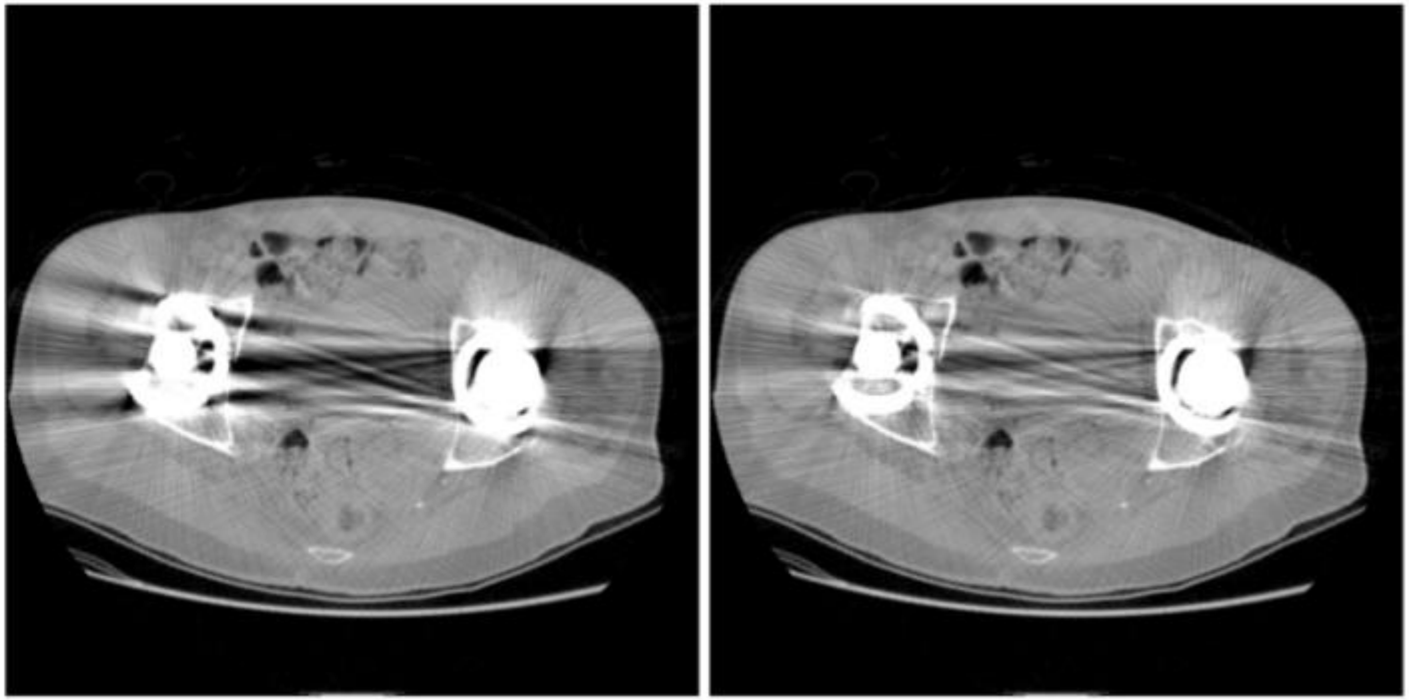


(a) (b)

Metal artifacts

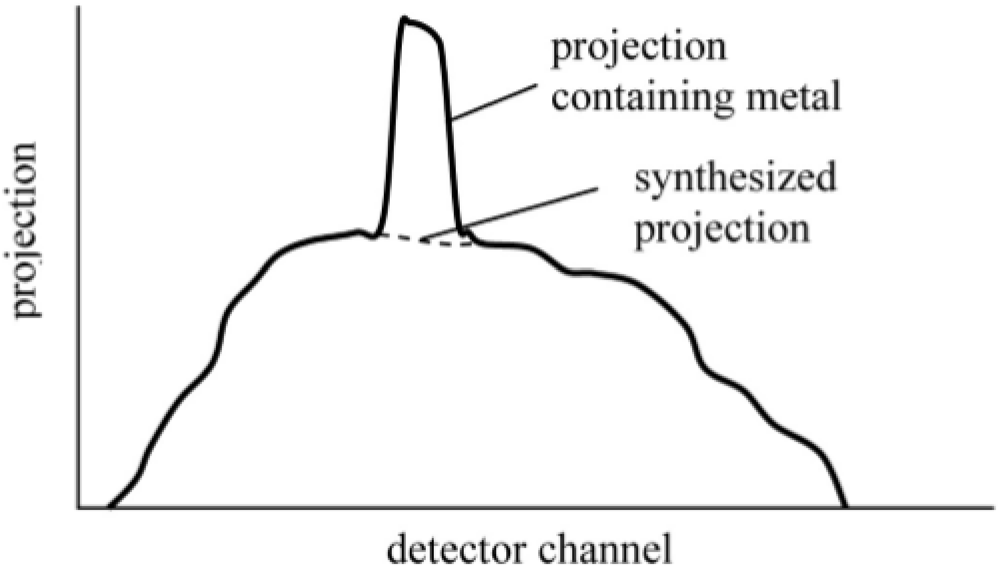
- This type of artifact can vary significantly
- Metal object can produce beam hardening, partial volume, aliasing, under-range, overflow of the dynamic range
- Many of compensation approaches can be used to reduce

- Patient with Ti implants



(a) (b)

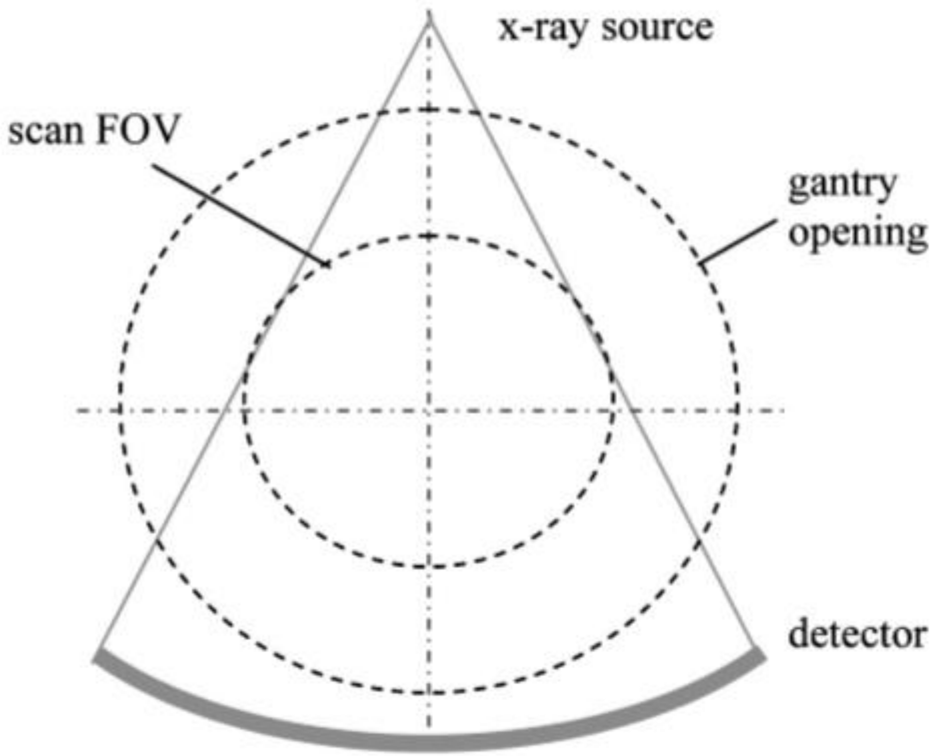
- Metal artifact suppression with synthesized projection samples



Incomplete projections

- This artifact occurs when a portion of a projection is not available for reconstruction
- Scanned object is partially outside the scan FOV
- Truncated projections produce brigh shading artifacts near the edge of truncation

- Schematic diagram of scan field-of-fiew and gantry opening

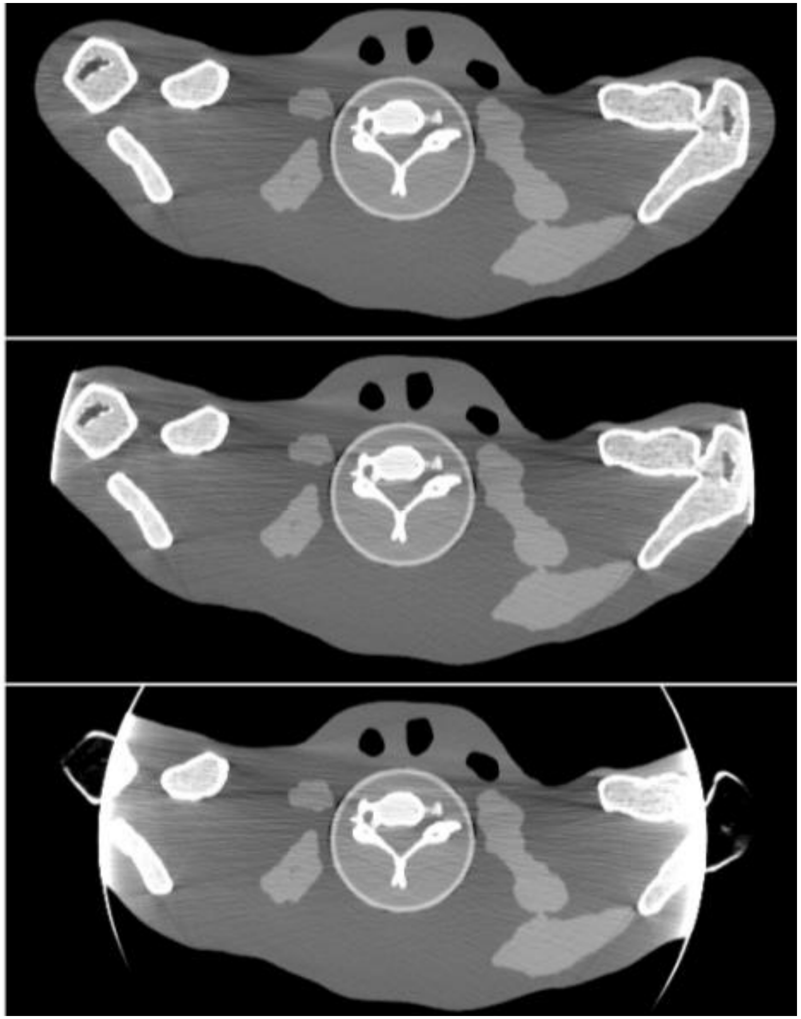


- Projection truncation

(a)

(b)

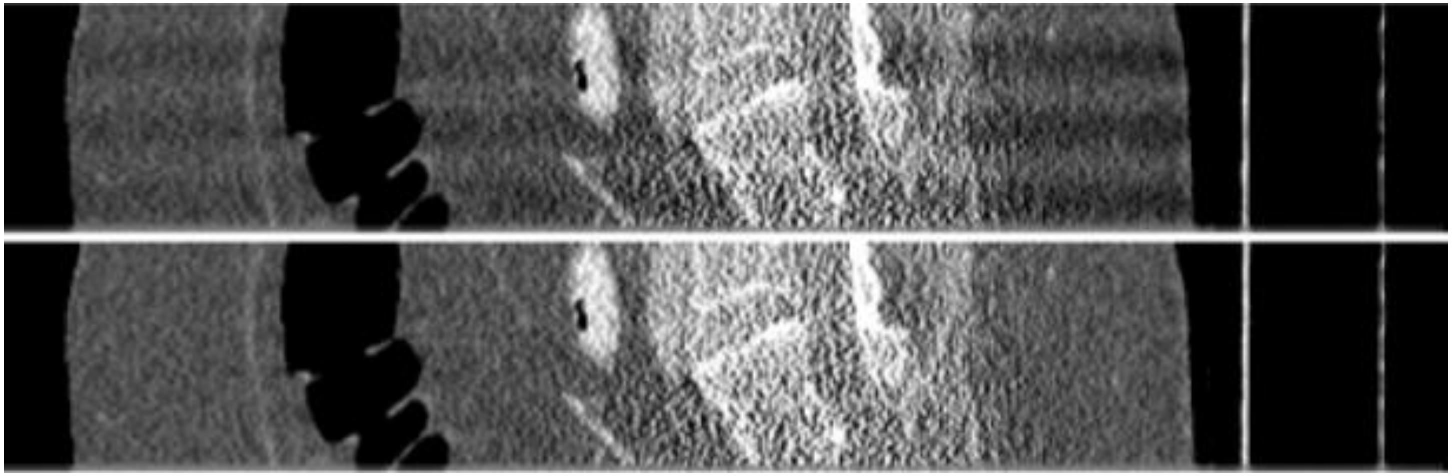
(c)



- Sagittal images of a patient scan blocked reference

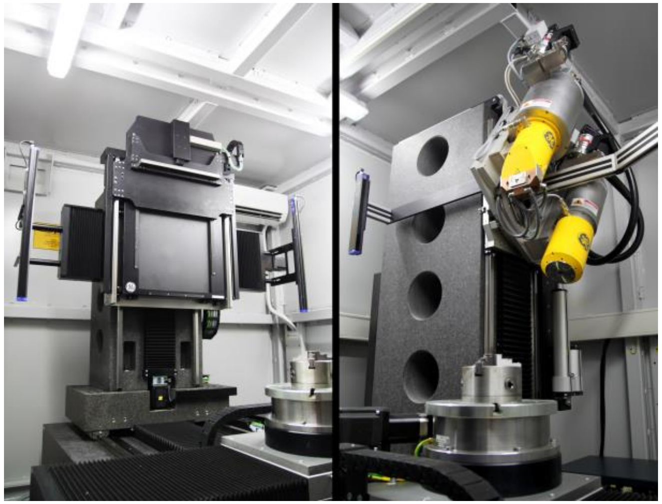
(a)

(b)



Tomographic artifacts induced by operator

- Very important role of operator
- Setting parametres of measurement-detector, X-ray source,…
- Centering of the sample, fixation of the sample



Thank you for your attention